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ROCKET OBSERVATIONS OF HIGH LEVEL MERIDIONAL FLOW OVER NORTH AMERICA DURING 1960 AND 1961

WILLIAM E. HUBERT*, Commander, U.S. Navy

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ABSTRACT

The relatively large number of meteorological rocket soundings made in the United States during 1960 indicate the meridional flow at 55 km. to be predominantly northward. A fewer number of soundings from Alaska and Canada for the same year also show a tendency for weak poleward flow at the same level but reveal stronger equatorward flow centered near 35 km. The data available from 1959, 1960, and 1961 indicate that the mean meridional flow did not reverse direction from summer to winter with the observed reversal of mean zonal flow at high levels. Mean annual meridional wind profiles for Point Mugu, Calif. for the years 1960 and 1961 are nearly identical.

1. INTRODUCTION

In recent years considerable effort has been expended toward improving our knowledge of mean circulation patterns in the stratosphere and mesosphere. This work has been stimulated by an increasing number of direct and indirect observations of wind, temperature, and density in these regions. Some meridional cross sections of mean zonal winds have been published recently by Murgatroyd [5] and Batten [1], but relatively little has been attempted in the way of mean meridional flow sections at high levels.

Goldie [2], Kellogg and Schilling [3] and Palmer [6] have all commented on the importance of more work on the meridional circulation problem, and several different models have been proposed. Most of these models of horizontal and vertical flow in the meridian plane were based upon certain theoretical considerations backed up by a few observations, frequently indirect.

The Meteorological Rocket Network (Webb et al. [7]) has provided the first opportunity to construct high level cross sections from a number of direct wind observations. In this paper an attempt is made to incorporate the North American rocket sounding data into a cross section of meridional flow for 1960. In addition, brief comment is made on the variability from season to season at two typical stations and on the similarity in mean meridional flow profiles at Point Mugu, Calif., for 1960 and 1961.

2. DATA

Meteorological rocket stations used in this study were Fort Greely, Alaska (64°00′ N.); Fort Churchill, Canada (58°47′ N.); Wallops Island, Va. (37°50′ N.); Point Mugu, Calif. (34°07′ N.); White Sands, N. Mex. (32°23′ N.); and Cape Canaveral, Fla. (28°14′ N.). Longitudes range from 80° to 145° W. These six stations were chosen because they contributed to the best overall data coverage. The proposed firing schedule of one launch per weekday for 1 month each season was not achieved by any station and several were even unable to make any launches during a whole season. Nevertheless, the observations that were made provided valuable, new information and should, in the author's opinion, be used to the utmost now. At $1,500 per launch for the rocket and instrument alone, it may take several years to build an optimum network capable of maintaining a regular schedule, even over North America.

For the mean cross section, meridional components were read from the published wind profiles (Data Report of

*Any opinions expressed by the author are his own and do not necessarily reflect the views of the Navy Department at large.

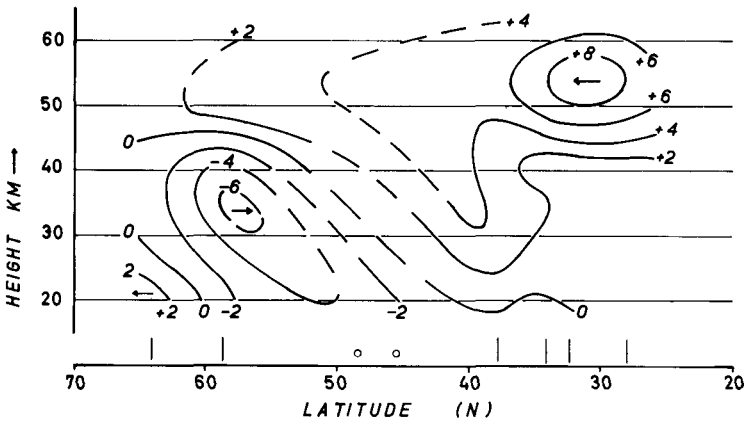

FIGURE 1.—Cross section of mean meridional winds (meters per second) for 1960. Locations of rocket and balloon stations are indicated by poles and circles above the latitude scale.

the Meteorological Rocket Network) at the 20-, 30-, 40-, 50-, and 60-km. levels. No attempt was made to weight the data to account for gaps in the firing schedule. Balloon data from St. Cloud and International Falls were used to verify the general pattern at lower levels near 50° N. Frequency histograms with class intervals of 5 m.p.s. were constructed to obtain means and to point out seasonal variations. Although data through the end of 1961 were available from Point Mugu, tabulations from the other stations have been received only through the spring firings for that year.

3. MERIDIONAL CROSS SECTION FOR 1960

Figure 1 shows the mean meridional wind flow analysis (in meters per second) constructed from the rocket soundings made during 1960. The locations of the six rocket and two balloon stations utilized in this section are indicated above the latitude scale at the bottom of the figure. Obviously, an active rocket station in the

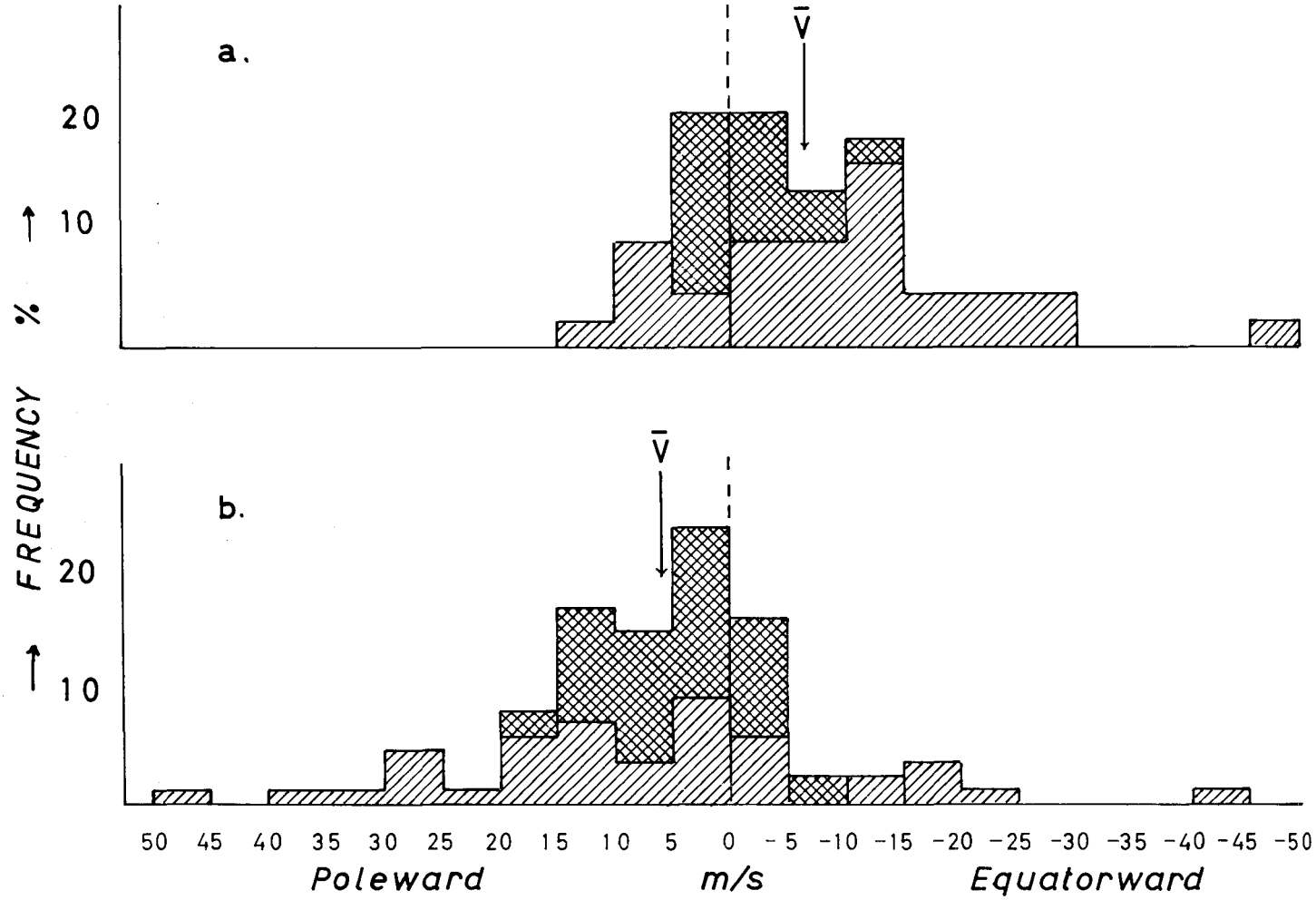

FIGURE 2.—Frequency distribution (percent) of meridional wind components (meters per second) determined from rocket measurements at (a) 35 km. for Fort Churchill, Canada and (b) 55 km. for Point Mugu, Calif. Winter, hatched; summer, cross-hatched. Data for 1959, 1960, and 1961.

Great Lakes area of the United States would add greatly to the picture and should be given high priority in network expansion.

Perhaps the most interesting and definitely the best-substantiated feature in this section is the strong poleward maximum near 55 km. revealed by all of the United States stations. In spite of the fact that two of the stations are on the east coast and two in the southwestern area (a longitudinal difference of almost 40°) their mean meridional wind profiles are all very similar. The few high level observations from Forts Greely and Churchill also indicate a mean poleward flow at 50 km. The cross section therefore shows the poleward current as being continuous although its validity is doubtful.

The equatorward maximum shown at lower levels near 60° N. is based on limited rocket data. High level balloon soundings indicate that the winter anticyclone over the Gulf of Alaska is frequently predominant enough to give a mean annual equatorward flow over central Canada. If real, the two meridional circulation features taken together would point to strong meridional convergence in a broad latitudinal zone over northern North America. Even disregarding the equatorward branch and the sign of the poleward flow at 50 km. farther north, the strong poleward cell over the United States would still give indication of meridional convergence and probably considerable subsidence in the polar mesosphere at the latitudes and longitudes covered here.

4. SEASONAL VARIATION

In an earlier paper Masterson, Hubert, and Carr [4] showed that at Point Mugu the meridional flow did not exhibit a seasonal reversal except below 30 km. (and possibly at heights above the cross section presented here). In order to test this finding with a larger number of observations, frequency distributions were constructed for winter (October–March) and summer (April–September) for stations near the maxima shown in the cross section. Figure 2 contains the distributions of observed meridional wind components for all rocket soundings reaching (a) 35 km. at Fort Churchill and (b) 55 km. at Point Mugu. In order to obtain a more representative picture, data from 1959, 1960, and 1961 were used in the graphs.

At Point Mugu the absence of a seasonal reversal in meridional flow at the levels studied here is quite clear. Over Fort Churchill at 35 km. the summer flow appears to be weaker but is still southward in the mean. The fact that the meridional wind did not follow the zonal wind in reversing direction from summer to winter is interesting. If data from a worldwide network continue to bear out this result, future circulation models must explain this difference.

5. ANNUAL VARIATION AT POINT MUGU

Figure 3 represents the mean meridional wind profiles at Point Mugu, Calif. for 1960 and 1961. Only rocket data were used to construct the profiles, and means were computed at 10,000-ft. intervals to obtain more detail. The similarity between the two years is striking. It is interesting to note the weak equatorward flow obtained at 40 km. during 1961 and the double maximum near 55 km. for both years. Since Point Mugu firings are conducted toward the southwest, the latter phenomenon may be explained by a bias introduced near the very top of each sounding. If one type of rocket consistently reaches apogee near 55 km. and a second type somewhat higher, momentum of the payload at sensor ejection may lead to a slight dip in the profile.

A discussion of annual variation at other stations will have to await publication of more observations. Based on the similarity found at Point Mugu, one would be tempted to expect only minor changes to appear at the other United States stations for 1960–61.

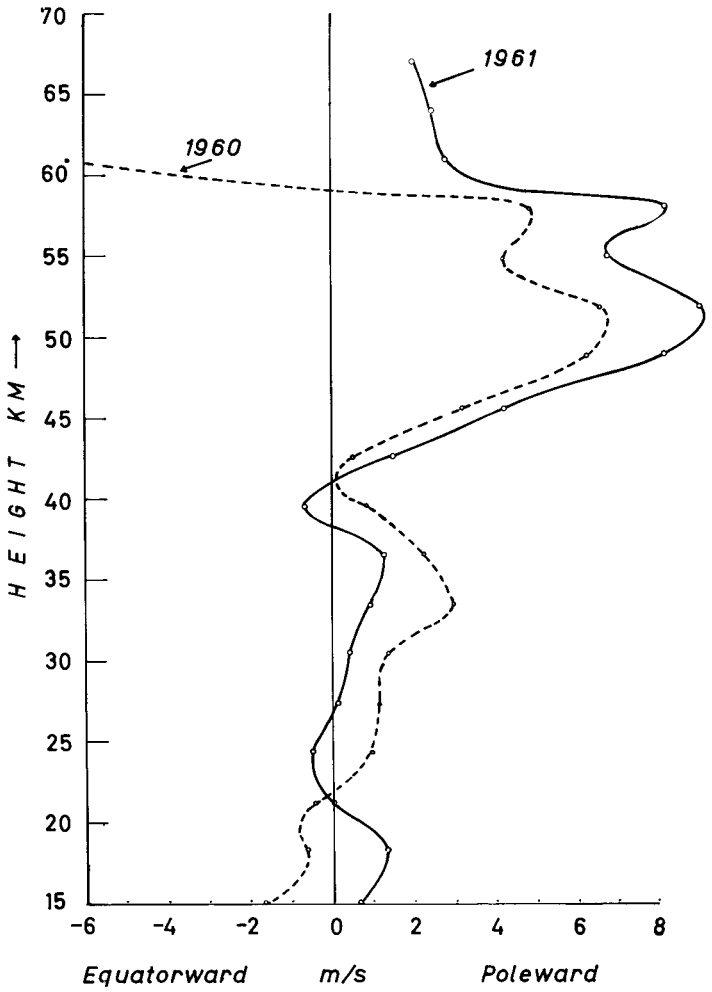

FIGURE 3.—Profiles of mean annual meridional wind components (meters per second) from rocket soundings at Point Mugu, Calif.

6. CONCLUSIONS

From the results shown here, one can say that in 1960 there was strong poleward flow over most of the United States near 55 km. and probably equatorward flow centered near 35 km. over the north-central part of the continent. In addition, there was evidently no seasonal reversal in the meridional flow during this period, and at Point Mugu little change in the mean meridional flow profiles for the two years for which data are available.

We know that the zonal winds go through a marked reversal at these levels with westerlies in winter and easterlies in summer. From this fact and certain radiational and frictional considerations, Kellogg and Schilling [3] deduced that the meridional flow should be directed toward the winter pole above the tropopause with sinking motion over the pole leading to low-level outbreaks of cold air in winter. Their model demands a seasonal reversal in the flow along the meridians. The results from the very limited area studied here do not confirm such a reversal.

Based upon meridional cross sections for density, Goldie [2] derived a circulation model composed of three cells in the vertical. The uppermost of these calls for equatorward flow in both summer and winter near 35 km. and presumably poleward flow somewhere above 40 or 50 km. The limited sector covered here gives evidence to support this flow.

It should be reiterated that these three figures are based upon a small data sample from a limited area, and that only a global network of rocket stations can give a complete picture of meridional circulation at high levels. International expansion of the Meteorological Rocket Program should be encouraged.

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